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(54) **MULTI-LOOP PHASE LOCK LOOP FOR CONTROLLING JITTER IN A HIGH FREQUENCY REDUNDANT SYSTEM**

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(58) **Field of Search** **331/17, 1 A, DIG. 2, 331/18, 25; 375/376; 327/147, 148, 149, 156, 159**

4,920,320 A * 4/1990 Matthews 331/17 XY
5,748,569 A 5/1998 Teodorescu et al. 368/118
6,097,777 A * 8/2000 Tateishi et al. 375/376
6,259,328 B1 * 7/2001 Wesolowski 331/14

* cited by examiner

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(57) **ABSTRACT**

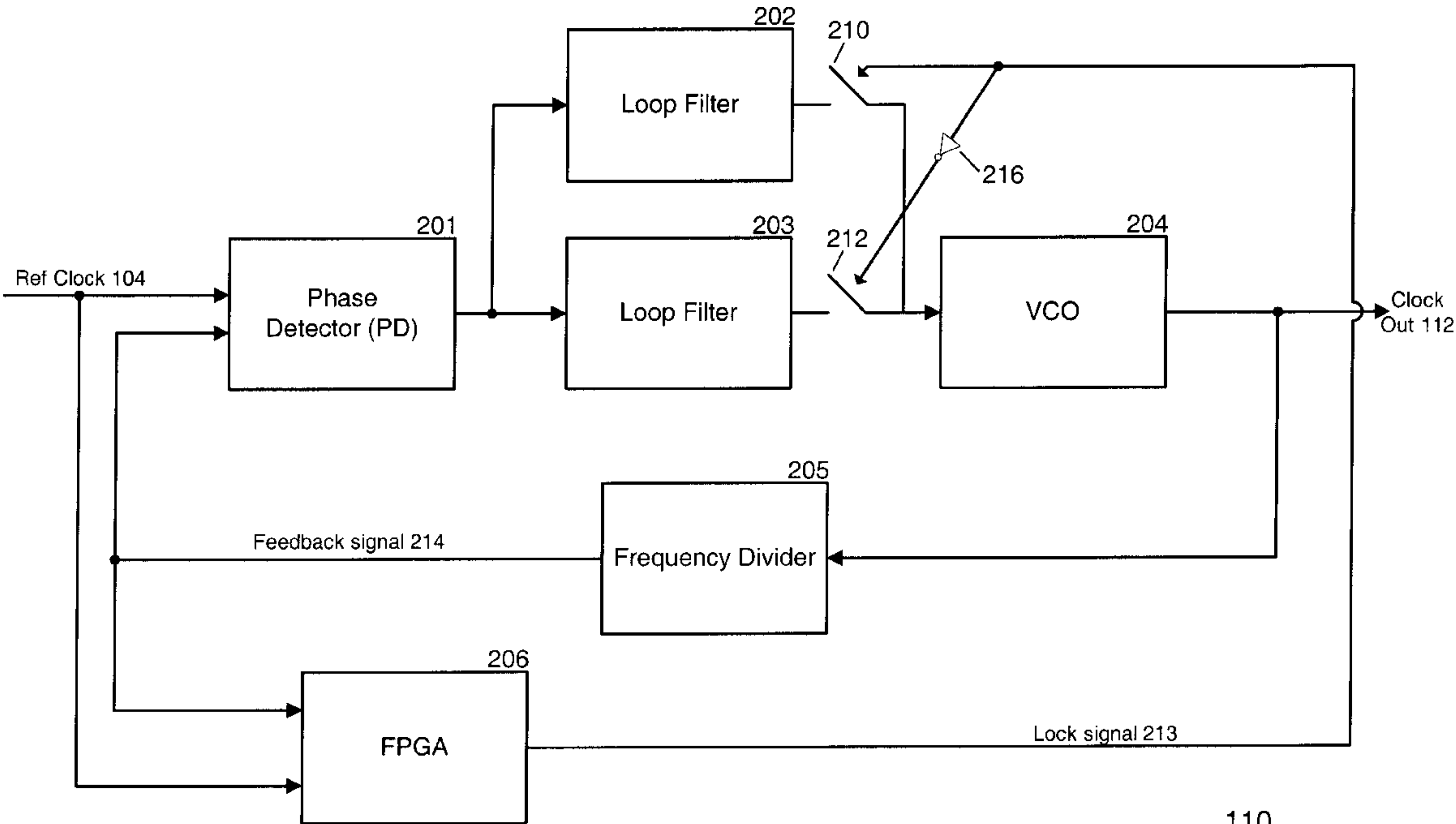
A multi-loop phase lock loop (PLL) contains multiple loop filters, each having different bandwidths. The multi-loop PLL receives one of multiple high-frequency clock signals as an input. A phase detector outputs a signal, based on the phase difference between the high-frequency clock signal and a feedback signal to the loop filters. A voltage controlled oscillator generates an output clock signal based on signals received from the loop filters. During a clock switch over sequence between the multiple high-frequency input clock signals, the multi-loop PLL uses one of its loop filters with a wide bandwidth to quickly lock the input clock signal. Once the clock signal is locked, a narrower bandwidth loop filter in the PLL is then used to reduce jitter in the locked signal.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,007,429 A * 2/1977 Cadalora et al. 331/17

21 Claims, 3 Drawing Sheets



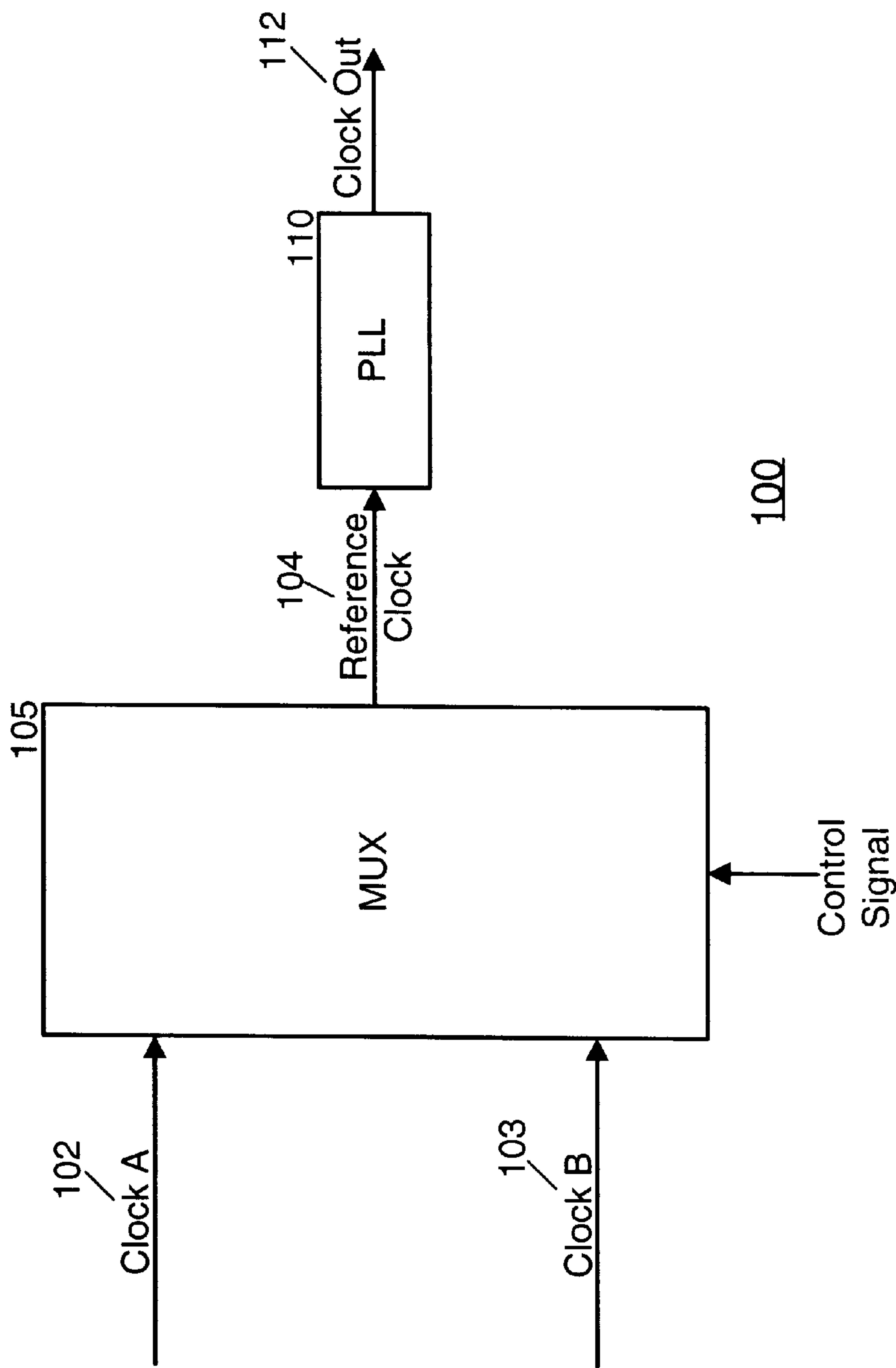


Fig. 1

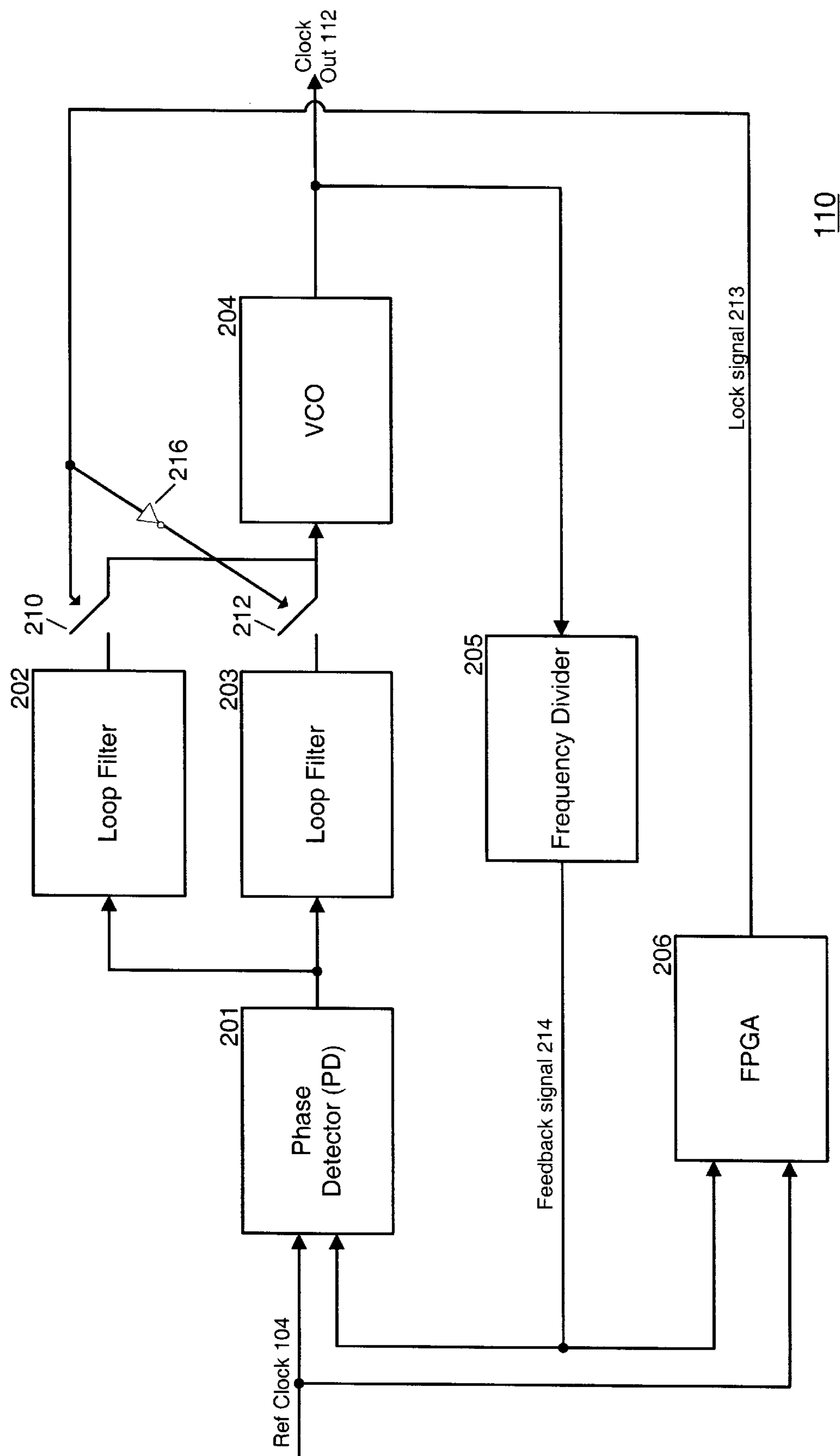


Fig. 2

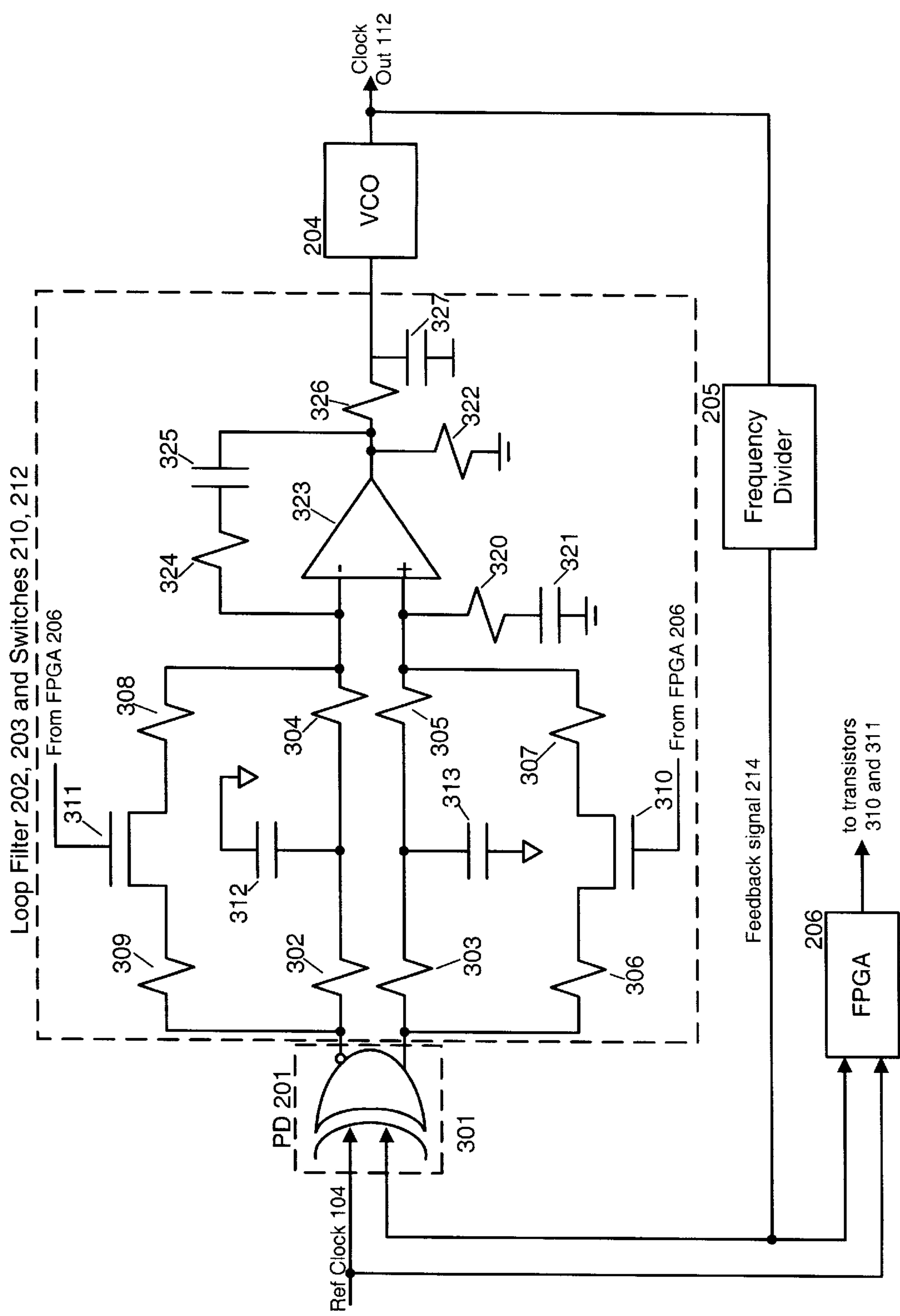


Fig. 3

MULTI-LOOP PHASE LOCK LOOP FOR CONTROLLING JITTER IN A HIGH FREQUENCY REDUNDANT SYSTEM

BACKGROUND OF THE INVENTION

A. Field of the Invention

The present invention relates generally to timing circuitry, and more particularly, to circuitry for high frequency clock alignment and switching.

B. Description of Related Art

Synchronous circuits are circuits that perform operations in step with a clock signal. For example, a clock source can be used in conjunction with a communication bus to provide a synchronous communications link between a sourcing device and one or more receiving devices. In a source synchronous communications link, the source device provides a source clock signal that the receiving device uses to synchronize the reading of data from the communications link.

Designs for mission critical systems must provide reliability. Redundancy can be built into a mission critical system to increase reliability. For example, redundant timing signals may be used in high performance telecommunications systems, such as high performance network routers. Such systems may include systems that have redundant, high frequency clock signals that receive and transmit data over optical carriers such as those conforming to the OC-48 or OC-192 synchronous optical network standard. In these systems, when an error is detected in the active clock, the redundant clock is switched to take over the role of the active clock.

Problems can arise when switching between high-frequency primary and redundant clock signals and when initially turning on the high-frequency clock signal. The high frequency of the clocks can make it difficult for the receiving system to obtain acquisition ("lock") of the newly activated clock, because of the low phase-noise requirement of the high frequency clocks. Additionally, the high-frequency clock must filter jitter from the input reference clock signal. Finally, switch-over between the two clock signals may cause glitches.

Accordingly, there is a need in the art to be able quickly lock onto a new clock signal or a newly switched high-frequency clock signal while reducing jitter and glitches caused by clock signal cross-over.

SUMMARY OF THE INVENTION

Systems and methods consistent with the present invention address this and other needs through the use of a multi-loop phase locked loop.

More particularly, a first aspect of the present invention is directed to a redundant clock system comprising a number of elements, including input clock signals and a multiplexer connected to receive the input clock signals and a control signal. The multiplexer outputs one of the input clock signals as a reference clock signal in response to the control signal. Additionally, a phase locked loop circuit is connected to receive the reference clock signal from the multiplexer. The phase locked loop circuit includes a first loop filter and a second loop filter. The first loop filter has a first bandwidth for initially locking onto the reference clock signal. A second loop filter has a second bandwidth, less than the first bandwidth. The second loop filter corrects for jitter in the reference clock signal after the first loop filter has locked onto the reference clock signal.

A second aspect of the present invention is directed to a circuit for removing jitter from a high frequency clock signal. The circuit includes a lock detection component, a first loop filter, a second loop filter, a switch, and a voltage controlled oscillator. The first loop filter receives a signal based on phase differences between the reference clock signal and the feedback clock signal and has a first predetermined bandwidth. A second loop filter receives the signal based on phase differences between the reference clock signal and the feedback clock signal and has a second predetermined bandwidth lower than the first predetermined bandwidth. The switch selects, based on the lock detection signal from the lock detection component, either the first loop filter or the second loop filter as the active loop filter.

A third aspect of the present invention is directed to a method of generating a clock signal based on one of a number of input clock signals. The method includes selecting one of the input clock signals as a reference signal and generating a first signal based on phase differences between the reference clock signal and a feedback signal. First and second loop filters process the first signal. The first loop filter is designed to lock the feedback signal to a reference clock signal. The second loop filter reduces jitter in the locked signal.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate an embodiment of the invention and, together with the description, explain the invention. In the drawings,

FIG. 1 is a block diagram illustrating, at a high level, a redundant clock system;

FIG. 2 is a block diagram illustrating an exemplary implementation of a phase lock loop component consistent with the present invention; and

FIG. 3 is an electrical diagram illustrating an exemplary implementation of loop filters and a phase detector consistent with the present invention.

DETAILED DESCRIPTION

The following detailed description of the invention refers to the accompanying drawings. The same reference numbers in different drawings identify the same or similar elements. Also, the following detailed description does not limit the invention. Instead, the scope of the invention is defined by the appended claims and equivalents.

As described herein, a multi-loop phase lock loop (PLL), containing multiple phase locked loop filters, each having different bandwidths, receives one of multiple high-frequency clock signals as an input. During clock start-up or upon a clock switch over sequence, the multi-loop PLL uses the wide bandwidth loop to quickly lock the input clock signal. Once the clock signal is locked, a narrower bandwidth loop filter in the PLL can then reduce jitter in the locked signal. Alternatively, during a clock switch over, if the new clock signal is enough in phase to the old clock signal, the multi-loop PLL may immediately use the narrow band PLL to reduce jitter.

FIG. 1 is a block diagram illustrating, at a high level, a redundant clock system. System 100 includes a multiplexer 105 and a PLL circuit 110. System 100 receives two clock signals, labeled as "Clock A" 102 and "Clock B" 103. The multiplexer 105 selects one of the two clock signals 102 and 103 based on a control signal. The selected clock signal is passed to PLL circuit 110, as a reference clock signal 104,

and, after processing, output as “Clock Out” **112**. The input clock signals **102** and **103** may be, for example, clock signals of 19.44 MHz and the output clock signal **112** may be a 622.08 MHz signal. Input clock signal **102** and **103** may be based on a highly accurate clock source such as a SONET

Multiplexer **105**, in addition to merely selecting one of clocks **102** or **103** to output as reference clock **104**, may pre-process the selected clock signal to bring it more into phase with the old clock signal. In this situation, it may be easier for PLL **110** to lock onto the new clock signal. For example, multiplexer **105** may include delay lines that implement a variable amount of delay in input signals **102** or **103**. During clock switch over, multiplexer **105** may then introduce enough delay into the new clock signal to phase align the new clock signal to the old clock signal.

In general, a PLL is an electronic circuit that controls an oscillator so that it maintains a constant phase angle relative to a reference signal. PLL circuit **110** performs this function on reference clock **104** to thereby reduce jitter in clock out signal **112**. Additionally, when reference clock **104** is being switched over from clock A **102** to clock B **103** (or vice versa), or reference clock **104** is newly introduced to the system, PLL circuit **110** can quickly lock onto the newly switched clock signal and then begin high precision jitter reduction.

FIG. 2 is a block diagram illustrating, in more detail, an exemplary implementation of PLL circuit **110**. The input clock signal, reference clock **104**, is received by phase detector **201**. Phase detector **201** also receives the output of frequency divider **205**, which reduces the frequency of clock out signal **112** by a predetermined factor (such as **32**). Phase detector **201** outputs a signal representing the difference in phases between its two input signals. This phase difference signal is fed to a first loop filter **202** and a second loop filter **203**. Through switches **210** and **212**, the output of the first or second loop filters **202** and **203** is selected and transmitted to voltage-controlled-oscillator (VCO) **204**. The output of VCO **204** is the output signal **112**, which is also transmitted back to the input of frequency divider **205**. FPGA (field programmable gate array) **206** receives the reference clock signal **104** and the feedback clock signal **214**, and outputs a lock signal **213** to switches **210** and **212**.

Phase detector **201** may include a phase detection mechanism that outputs a first state (e.g., logic high) when reference clock signal **104** and feedback signal **214** have the same logic state, and outputs a second state (e.g., logic low) when the these two signals are of different values. In this manner, the output of phase detector **201** is an indication of the phase difference between the two input clock signals **104** and **214**.

VCO **204** may include a surface acoustic wave (SAW) based VCO that generates clock out signal **112** based on its input control voltage. Clock out signal **112** can have a frequency that is a multiple of the reference clock frequency. For example, clock out signal **112** may be a 622.08 MHz signal and reference clock **104** may be a 19.44 MHz signal. In this situation, the multiplying factor is **32**. Other clock frequencies and multiplying factors may be used. Frequency divider **205** may be accordingly constructed to reduce the frequency by a factor of **32** so that feedback signal **214** and reference clock signal **104** are the same frequency. A SAW based VCO is desirable as it tends to have a high “Q” value. SAW based VCOs are known in the art and will, therefore, not be described further herein.

FPGA (field programmable gate array) **206** generates lock signal **213** in response to feedback signal **214** and reference

clock **104**. In particular, when reference clock **104** has been acquired by feedback signal **214** (i.e., it is locked), FPGA **206** activates lock signal line **213**. Circuits for generating signals based on a lock detection comparison are well known in the art, and thus FPGA **206** will not be described further herein.

Narrow bandwidth PLLs provide better phase noise characteristics than wider bandwidth PLLs when in the presence of noisy reference clocks. Wider bandwidth PLLs, however, have better acquisition and tracking characteristics. PLL circuit **110**, at different times, may effectively function as both a narrow bandwidth PLL and a wide bandwidth PLL. Initially, PLL **110** acts as a wider bandwidth PLL. When the clock signal is locked, PLL **110** begins to operate as a narrow bandwidth PLL. In this manner, PLL **110** can quickly lock and begin to reduce phase noise in the input reference clock signal.

More particularly, loop filter **202** may include a wide band loop filter (e.g., a 1 kHz bandwidth filter) and loop filter **203** may include a narrow band loop filter (e.g., a 17 Hz bandwidth filter). Lock signal **213** controls the operational state of switches **210** and **212** so that the switches are in opposite states (illustrated in FIG. 2 by inverter **216** leading to the control node of switch **212**). In operation, FPGA **206** initially outputs a lock signal **213** that indicates that a signal lock is not found (e.g., a logic low value), which causes switch **210** to connect loop filter **202** to VCO **204**. When FPGA **206** determines that the feedback signal **214** and the reference clock **104** are locked, FPGA **206** changes the state of the lock signal **213**, causing switches **210** and **212** to reverse state. Accordingly, the narrow band loop filter, loop filter **203**, is connected to VCO **204** and the wide band loop filter, loop filter **202**, is disconnected from VCO **204**. Narrow bandwidth loop filter **203** then functions with VCO **204** to generate a low jitter clock out **112** signal.

The above-discussed switching between loop filters **202** and **203** may be implemented whenever reference clock signal **104** is initially turned on. In this situation, the new reference clock signal **104** will generally be difficult for the narrow band loop filter **203** to lock to the new signal. Accordingly, FPGA **206** will indicate a lack of lock, and the wider band loop filter **202** will begin to operate. During switch-over between one of redundant clock signals **102** or **103**, however, the new reference clock signal **104** may already be close enough to the old clock signal so that lock may be continuously maintained (this is particularly true when multiplexer **105** preprocesses the switched signal using variable length delay lines to remove phase difference.) In this situation, FPGA **206** will continue to maintain a positive lock signal **213**, and narrow band filter **203** will continuously operate.

FIG. 3 is an electrical diagram illustrating an exemplary construction of loop filters **202–203** and phase detector **201**.

Loop filters **202** and **203** are shown conceptually in FIG. 2 as two independent elements switched in and out by two distinct switches **210** and **212**. However, as shown in the actual physical implementation of FIG. 3, loop filters **202** and **203** may be implemented as a single combined circuit that uses a single switch implemented by transistors **310** and **311**.

Phase detector **201** may be implemented as exclusive-OR (XOR) gate **301**. Two complimentary outputs are taken from XOR gate **301**, which are eventually fed into the input of differential amplifier **323**. An XOR gate has the property that it outputs an active value when its input signals have different values—that is, when the two input clock signals

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104 and **214** are out of phase with one another. In general, an XOR based phase detector may have more difficulty locking than conventional phase-frequency detectors. However, an XOR gate has less deadband and therefore less overall noise than a conventional phase-frequency detector. Because XOR gate **301** is used in conjunction with loop filters **202** and **203**, the fact that XOR gate **301** may have more difficulty locking the signal is less of an issue, because the circuit has multiple bandwidth loops and can pick an appropriate bandwidth setting to help achieve lock.

Loop filter **202** may include resistors **306–309** connected in series to differential amplifier **323**. The pairing of resistors **306, 307** and **308, 309**, as opposed to using a single resistor in place of pairs **306, 307** or **308, 309**, isolates unwanted parasitic capacitance from transistors **310** and **311** from the narrow loop circuit, respectively. Transistors **310** and **311** either connect or disconnect loop filter **202** from circuit **110** based on the value of lock signal line **213**. Before FPGA **206** finds a signal lock, lock signal line **213** closes transistors **310** and **311**, connecting loop filter **202** to circuit **110**. When FPGA **206** detects a signal lock, it inverts the lock signal line **213**, which disconnects loop filter **202** from circuit **110** and allows the narrow band loop filter **203** to function. The narrow band loop filter **203** includes the serially-connected resistor pairs **302, 304** and **303, 305**. Filtering capacitors **312** and **313** are placed between each pair of resistors and its power supply.

Additionally, as shown in FIG. 3, differential amplifier **323** is surrounded by a number of circuit elements, including, for example: resistor **320** and capacitor **321** connected in series to one input of differential amplifier **323**; resistor **324** and capacitor **325** connected in series to the second input of differential amplifier **323** and to the output of differential amplifier **323**; resistor **322** connected between the output of differential amplifier **323** and ground; resistor **326**, connected between the output of differential amplifier **323** and VCO **204**; and capacitor **327**, connected between resistor **326** and VCO **204**.

As described above, a PLL circuit **110** effectively uses multiple loop filters to handle clock acquisition and jitter control during switching between high frequency clock sources and upon initial application of a high frequency clock source. Although the PLL circuit **110** has been described as receiving one of two reference clock signals, one of ordinary skill in the art will recognize that any number of redundant reference clock signals could be used. Additionally, PLL circuit **110** could be constructed with greater than two loop filters. For example, two wideband filters, one wider than the other, could be used to lock onto the reference signal by stepping down from the widest bandwidth filter to the narrower wideband filter.

The resistors and capacitors shown in FIG. 3 could be set to any number of different values to obtain appropriate operation of PLL circuit **110**. In general, the resistor and capacitor components shown in FIG. 3 are determined by the bandwidth and phase margin of the PLL. Since the VCO represents a pole at the origin, and the op-amp is configured as an integrator, a zero should be created so that the slope of the transfer function is falling at -20 dB per decade at unity gain. By adjusting the phase margin at unity gain, the responsivity of the loop can be adjusted from underdamped to overdamped response. In this design, given that multiple PLLs can be configured in tandem, so as to limit jitter peaking, an overdamped response is desirable.

The foregoing description of preferred embodiments of the present invention provides illustration and description,

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but is not intended to be exhaustive or to limit the invention to the precise form disclosed. Modifications and variations are possible in light of the above teachings or may be acquired from practice of the invention.

Although described as being primarily implemented in hardware, the present invention may be embodied in hardware and/or software (including firmware, resident software, micro-code, etc.). Furthermore, portions of the present invention may take the form of a computer program product on a computer-usable or computer-readable storage medium having computer-usable or computer-readable program code embodied in the medium for use by or in connection with an instruction execution system.

The scope of the invention is defined by the claims and their equivalents.

What is claimed is:

1. A circuit for removing jitter from a high frequency clock signal comprising:

- a first input clock signal line configured to receive a first input clock signal;
- a second input clock signal line configured to receive a second input clock signal;
- a multiplexer component configured to receive the first input clock signal and the second input clock signal and process at least one of the first and second input clock signals to bring the first and second input clock signals into phase with one another, the multiplexer component outputting one of the processed first and second input clock signals as a reference clock signal;
- a lock detection component connected to receive the reference clock signal and a feedback clock signal, the lock detection component detecting when the feedback clock signal is locked to the reference clock signal and outputting a lock detection signal in response to the detection;
- a first loop filter configured to receive a signal based on phase differences between the reference clock signal and the feedback clock signal, the first loop filter having a first predetermined bandwidth;
- a second loop filter configured to receive the signal based on phase differences between the reference clock signal and the feedback clock signal, the second loop filter having a second predetermined bandwidth lower than the first predetermined bandwidth;
- a switch configured to select the first loop filter as an active loop filter when the lock detection signal indicates that the feedback clock signal is not locked to the reference clock signal and the second loop filter as the active loop filter when the lock detection signal indicates that the feedback clock signal is locked to the reference clock signal; and
- a voltage controlled oscillator connected to an output of the first and second loop filters, the voltage controlled oscillator producing a clock out signal based on signals from the first and second loop filters.

2. The circuit of claim 1, wherein the clock out signal is used to derive the feedback clock signal.

3. The circuit of claim 1, wherein the lock detection signal indicates signal lock in response to the first loop filter locking the feedback clock signal to the reference clock signal.

4. The circuit of claim 3, wherein the second loop filter operates to reduce jitter in the high frequency clock signal.

5. The circuit of claim 1, wherein the voltage controlled oscillator includes a surface acoustic wave voltage controlled oscillator.

6. The circuit of claim 1, further comprising
a frequency divider configured to receive the clock out
signal and output the feedback clock signal, the fre-
quency divider generating the feedback clock signal by
reducing the frequency of the clock out signal by a
predetermined factor.
7. The circuit of claim 6, wherein the reference clock
signal has a frequency of 19.44 MHz and the clock out signal
has a frequency of 622.08 MHz.
8. The circuit of claim 7, wherein the frequency divider
reduces the frequency of the clock out signal by a factor of
32.
9. A redundant clock system comprising:
a plurality of input clock signal lines for carrying respec-
tive redundant input clock signals;
a multiplexer connected to receive the plurality of input
clock signals and a control signal and process at least
one of the plurality of input clock signals to bring the
input clock signals into phase with one another, the
multiplexer outputting one of the plurality of input
clock signals as a reference clock signal in response to
the control signal; and
a phase locked loop circuit connected to receive the
reference clock signal from the multiplexer, the phase
locked loop circuit including
a first loop filter, having a first bandwidth, for initially
locking onto the reference clock signal;
a second loop filter, having a second bandwidth less
than the first bandwidth, for correcting for jitter in
the reference clock signal after the first loop filter has
locked onto the reference clock signal; and
a lock detection component connected to receive the
reference clock signal and a feedback clock signal,
the lock detection component detecting when the
feedback clock signal is locked to the reference clock
signal and outputting a lock detection signal in
response, to the detection.
10. The redundant clock system of claim 9, wherein the
phase lock loop circuit further includes:
a voltage controlled oscillator connected to an output of
the first and second loop filters, the voltage controlled
oscillator producing a clock out signal based on signals
from the first and second loop filters, the clock out
signal being used to derive the feedback signal.
11. The redundant clock system of claim 10, wherein the
phase lock loop circuit further includes:
a switch configured to select the first loop filter as an
active loop filter when the lock detection signal indi-
cates that the feedback clock signal is locked to the
reference clock signal and the second loop filter as the
active loop filter when the lock detection signal indi-

- cates that the feedback clock signal is not locked to the
reference clock signal.
12. The redundant clock system of claim 11, wherein the
lock detection component detects when the feedback clock
signal is locked to the reference clock signal in response to
initial application of the reference clock signal.
13. The redundant clock system of claim 10, wherein the
voltage controlled oscillator includes a surface acoustic
wave voltage controlled oscillator.
14. The redundant clock system of claim 13, wherein the
phase lock loop circuit further includes:
a frequency divider configured to receive the clock out
signal and output the feedback clock signal, the fre-
quency divider generating the feedback clock signal by
reducing the frequency of the clock out signal by a
predetermined factor.
15. The redundant clock system of claim 14, further
including an exclusive-OR gate connected to receive the
reference clock signal and the feedback clock signal and
configured to generate an input to the first and second loop
filters based on phase differences between the reference
clock signal and the feedback clock signal.
16. The redundant clock system of claim 15, wherein the
reference clock signal has a frequency of 19.44 MHz, the
clock out signal has a frequency of 622.08 MHz, and the
frequency divider reduces the frequency of the clock out
signal by a factor of 32.
17. The circuit of claim 1, wherein the first and second
loop filters are differential filters.
18. The circuit of claim 1, further comprising:
an exclusive-OR gate connected to receive the reference
clock signal and the feedback clock signal and config-
ured to generate the signal based on phase differences
between the reference clock signal and the feedback
clock signal.
19. The system of claim 9, wherein the first and second
loop filters are differential filters.
20. The circuit of claim 1, wherein the multiplexer com-
ponent includes:
delay lines configured to process the at least one of the
first and second input clock signals by introducing
delay into the at least one of the first and second input
clock signals.
21. The system of claim 9, wherein the multiplexer
includes:
delay lines configured to process the at least one of the
plurality of input clock signals by introducing delay
into the at least one of the plurality of input clock
signals.

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